

Enhanced Particle Identification in Water-based Liquid Scintillator

Snowmass Early Career

Neutrino Frontier

July 24th, 2022

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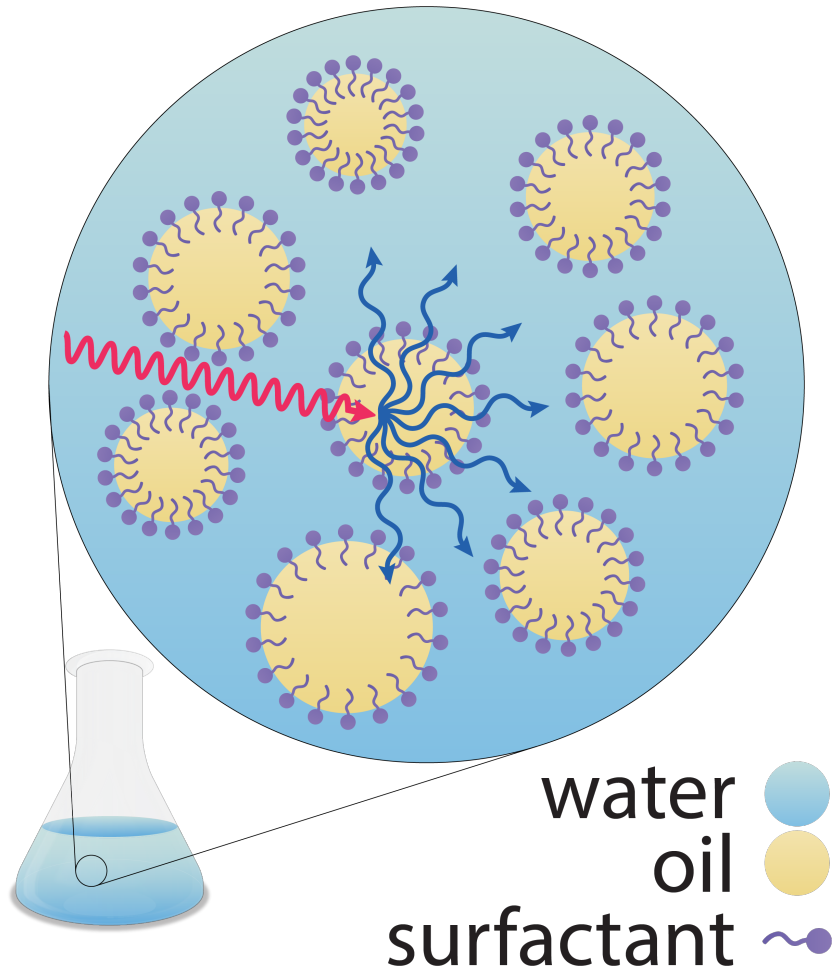


Overview

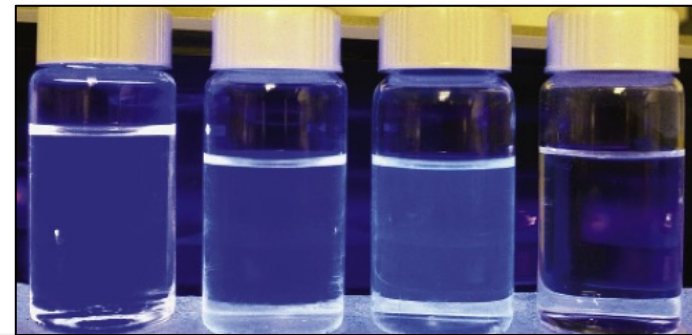
- Chemists at LLNL developed a new formulation of WbLS* with pulse-shaped discrimination for better particle identification.
- We currently have plans to utilize existing LLNL capabilities to characterize and reiterate on formulations for scaling to larger scale detectors.

*In this talk we define WbLS as a majority water complex.

Water-based Liquid Scintillator Developed by Brookhaven



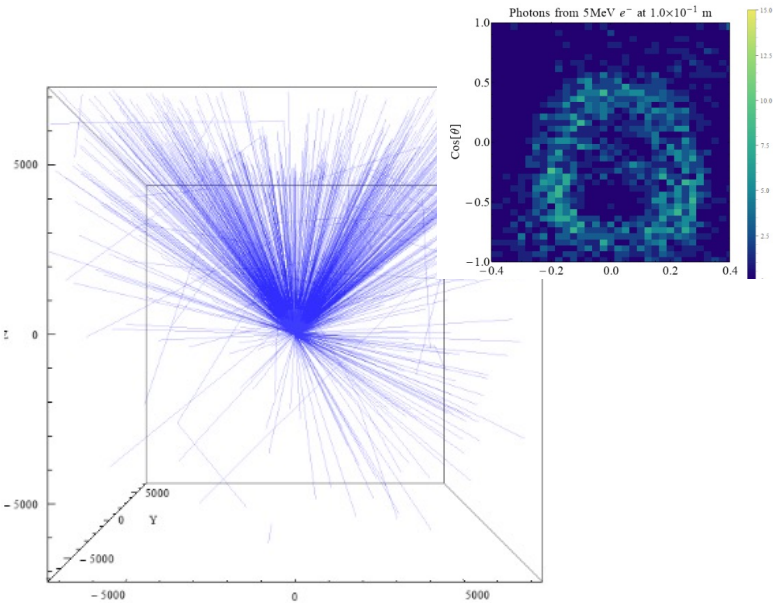
- Water-based liquid scintillator (WbLS) contains a scintillation phase (oil) dispersed in water, stabilized by a surfactant.
- This has already been demonstrated and developed by BNL and characterized by U.C. Berkeley and others over the past decade.



M. Yeh et al., **NIMA**, 2011

WbLS Best of Both Worlds

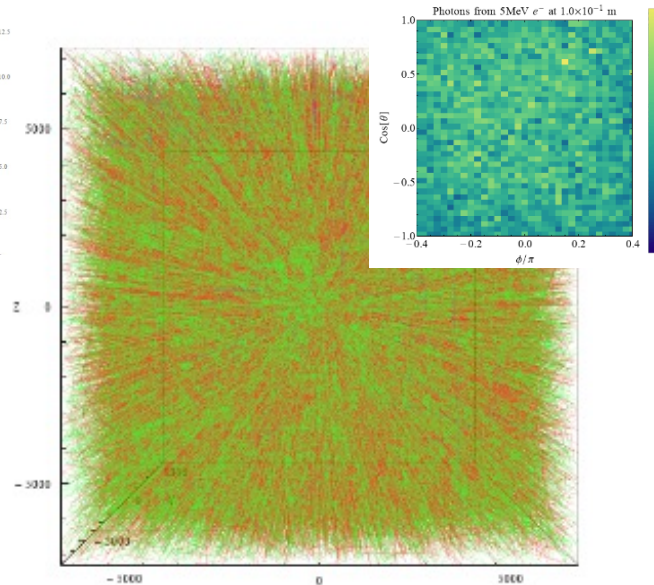
Water-Cherenkov Detectors



Advantages of Pure Water:

- Low attenuation
- Direction reconstruction
- Low Cost and Toxicity
- Scalability

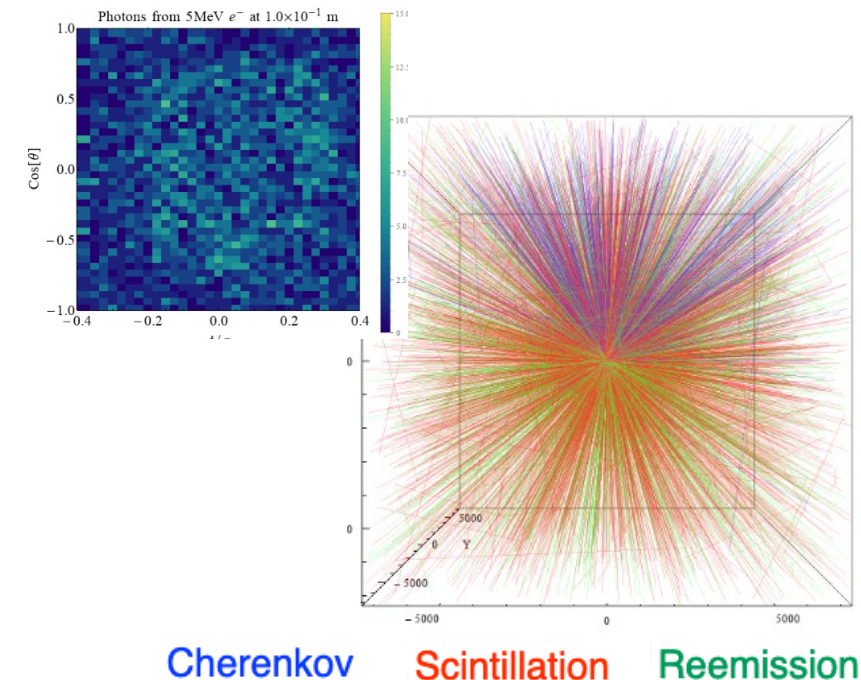
Scintillator Detectors



Advantages of Liquid Scintillator:

- High Light Yield
- Low Threshold Detection

Water-based Liquid Scintillator Detector

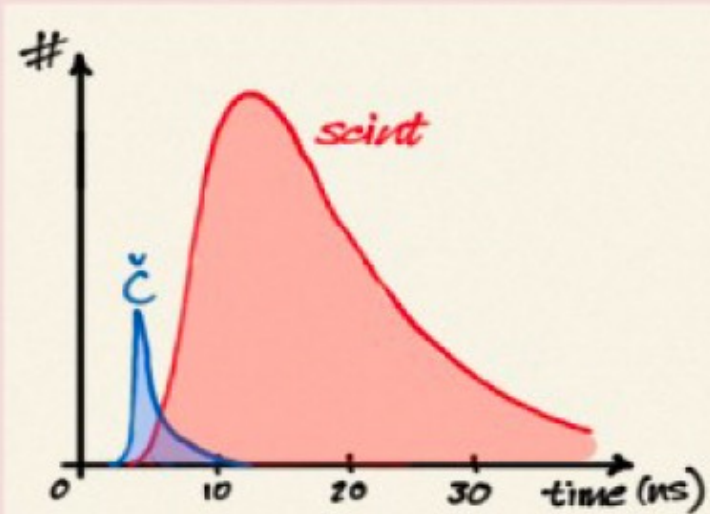


Best of both Worlds

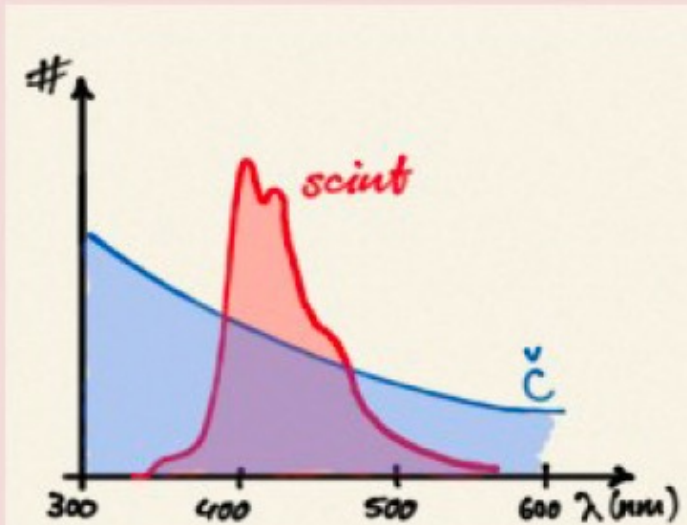
Images taken from Ben Land at U.Penn

Current Particle Identification in Large-Scale Detectors

Time



Wavelength



Angular Distribution

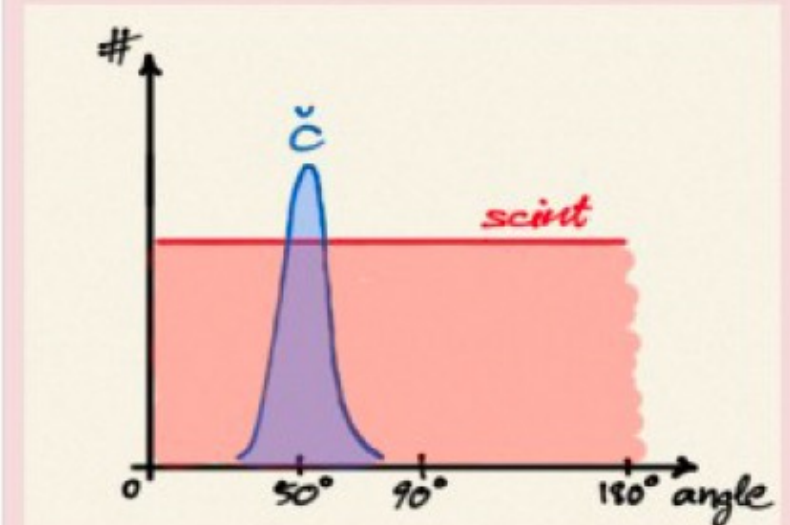


Image from Dr. Michael Wurm Johannes Gutenberg University Mainz

WbLS development at LLNL seeks to expand on PID techniques

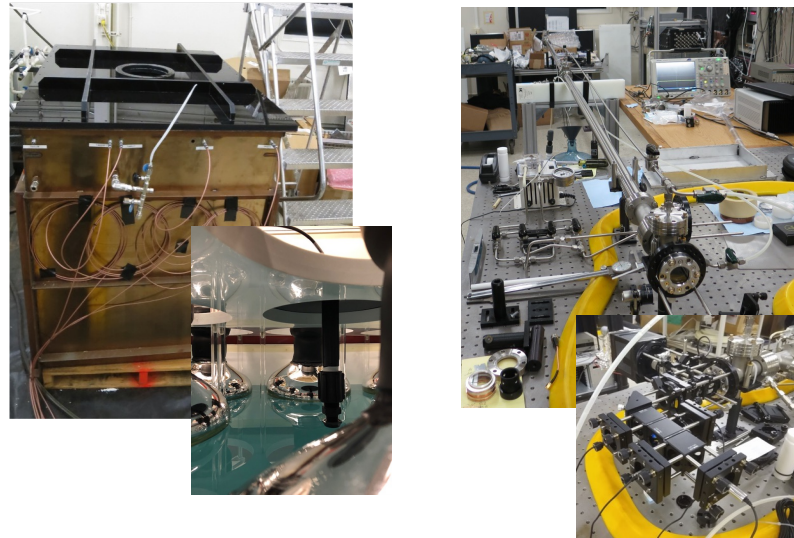
Why LLNL for WbLS Development

Extensive Scintillator Experience



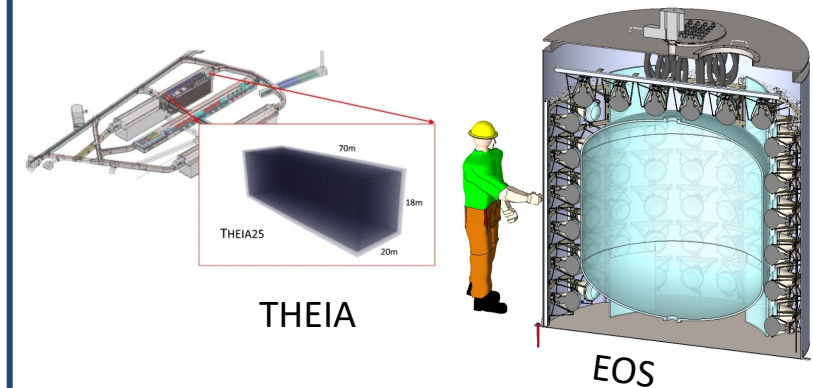
- LLNL is home to some of the best scintillator chemists in the world.
- LLNL has developed Li loaded plastics, Stilbene arrays, slow-liquid scintillators, and more.

Existing Equipment



- LLNL has an existing 1-ton media testbed for small scale studies.
- LLNL is also home to an attenuation and scattering arm that has been validated with DI water.

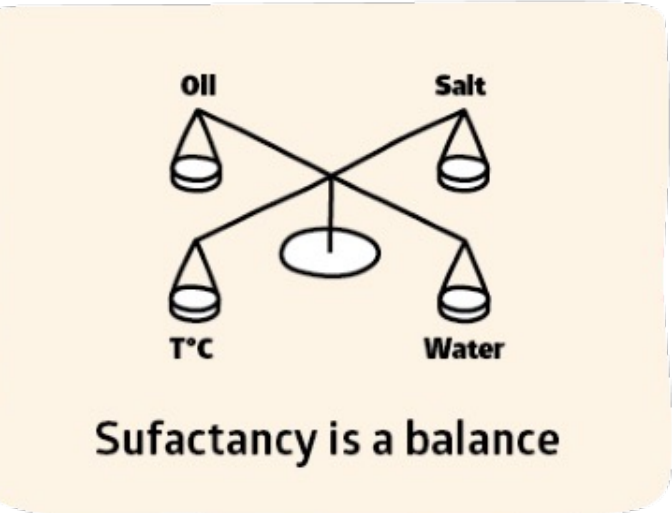
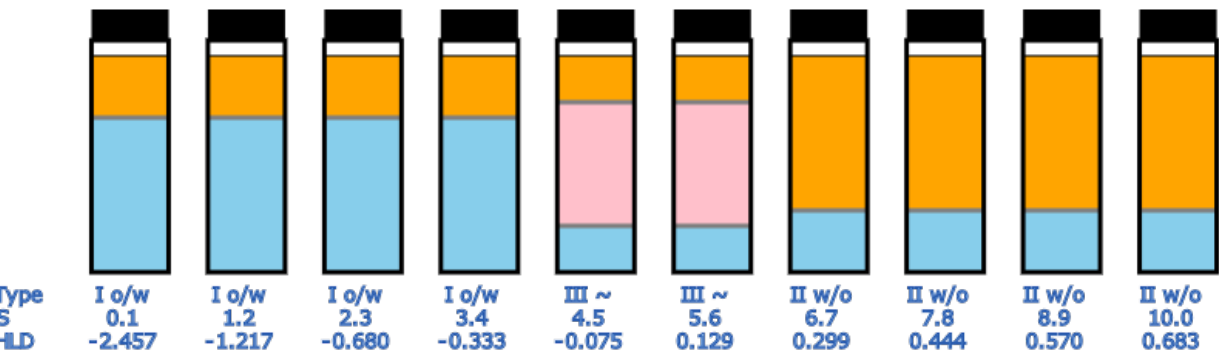
Collaborative Interface with other interest groups



- We share collaborators between this effort and that of EOS.
- Members of the local LLNL team are observers on the THEIA interest group.

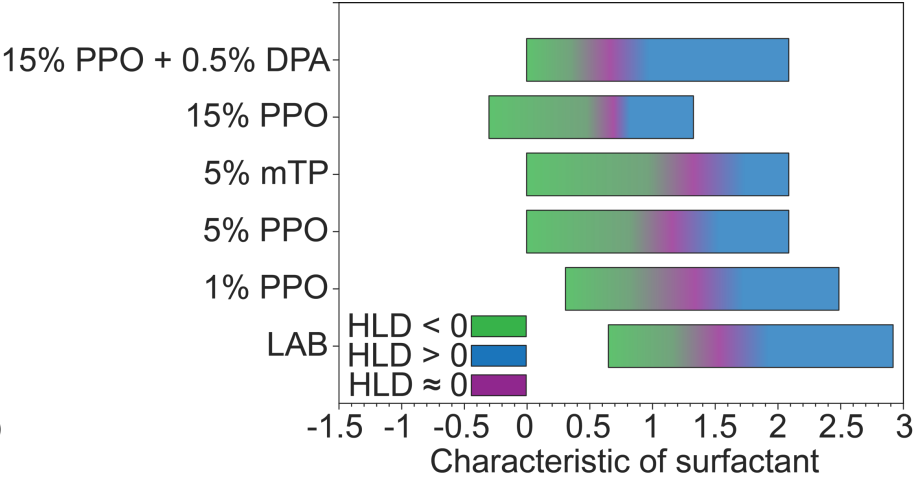
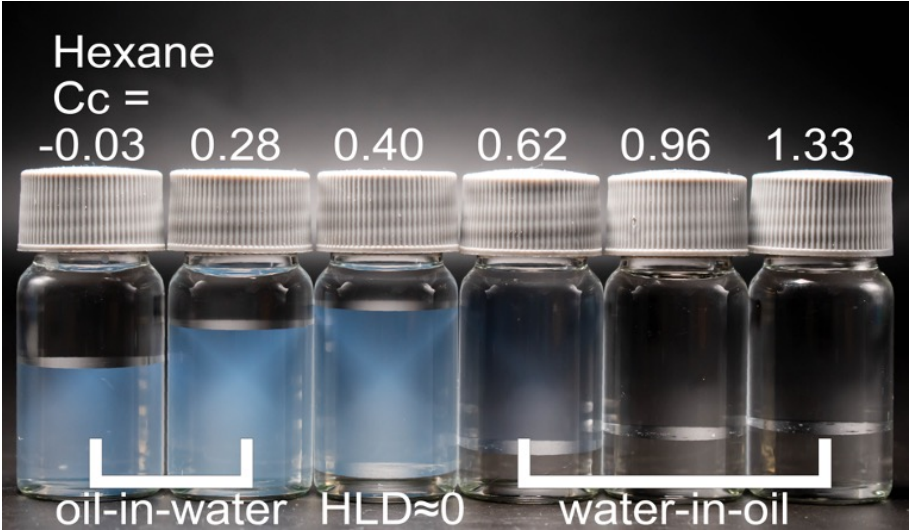
Hydrophilic-lipophilic difference

orange = oil phase (lower density); blue = water phase; pink = balanced



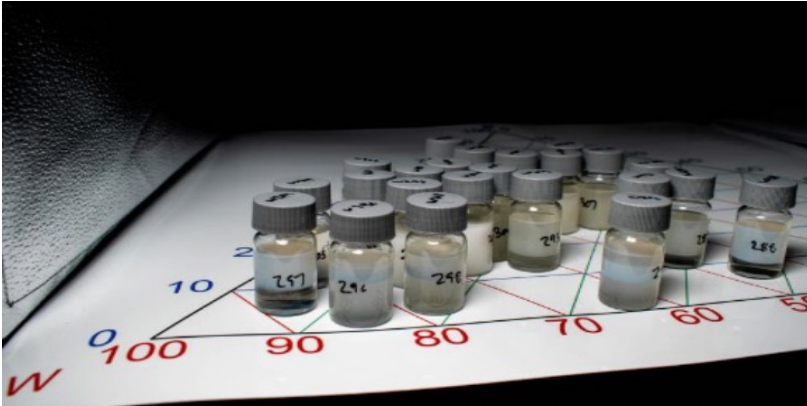
Each part of emulsion can be given a value:

- Characteristic of **surfactant**, C_c
- Effective characteristic of **oil**, EACN
- **Salt** concentration, S
- **Temperature**, T

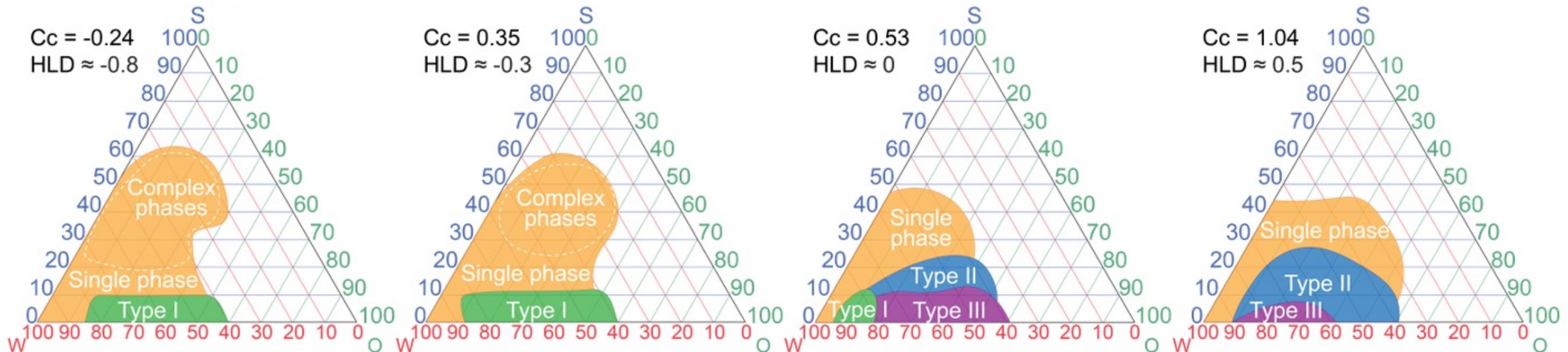


“Practical Surfactant Science” <https://www.stevenabbott.co.uk/practical-surfactants/index.php>
 Ford, Michael J., et al. NIMA (2022): 166854.

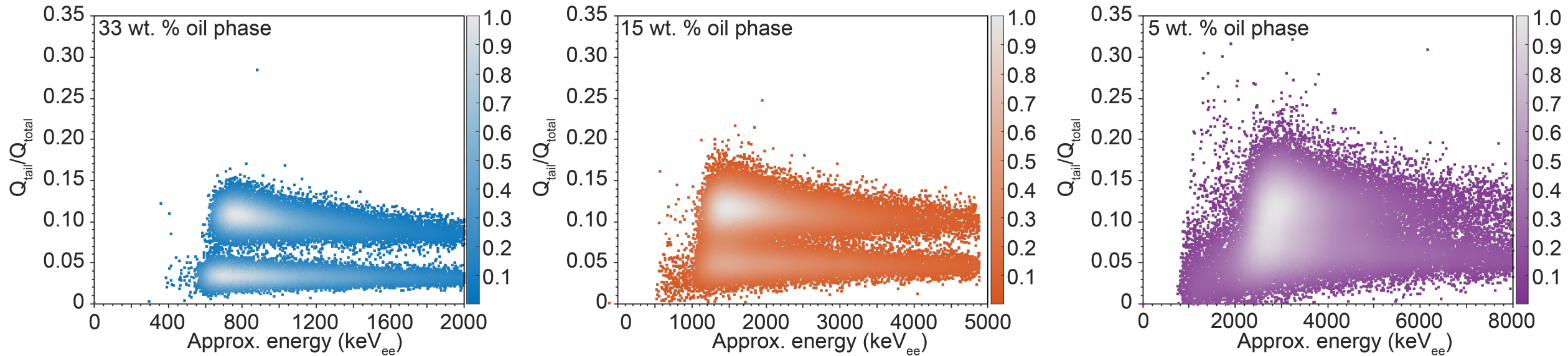
An empirical approach to stabilize emulsions



- Through this work we have developed a way to fully characterize the stability of each sample by understanding the phase changes as a function of its constituent parts.
- This empirical formulation compared with experimental plans will pave the way for a "tunable" WbLS depending on the required goals.

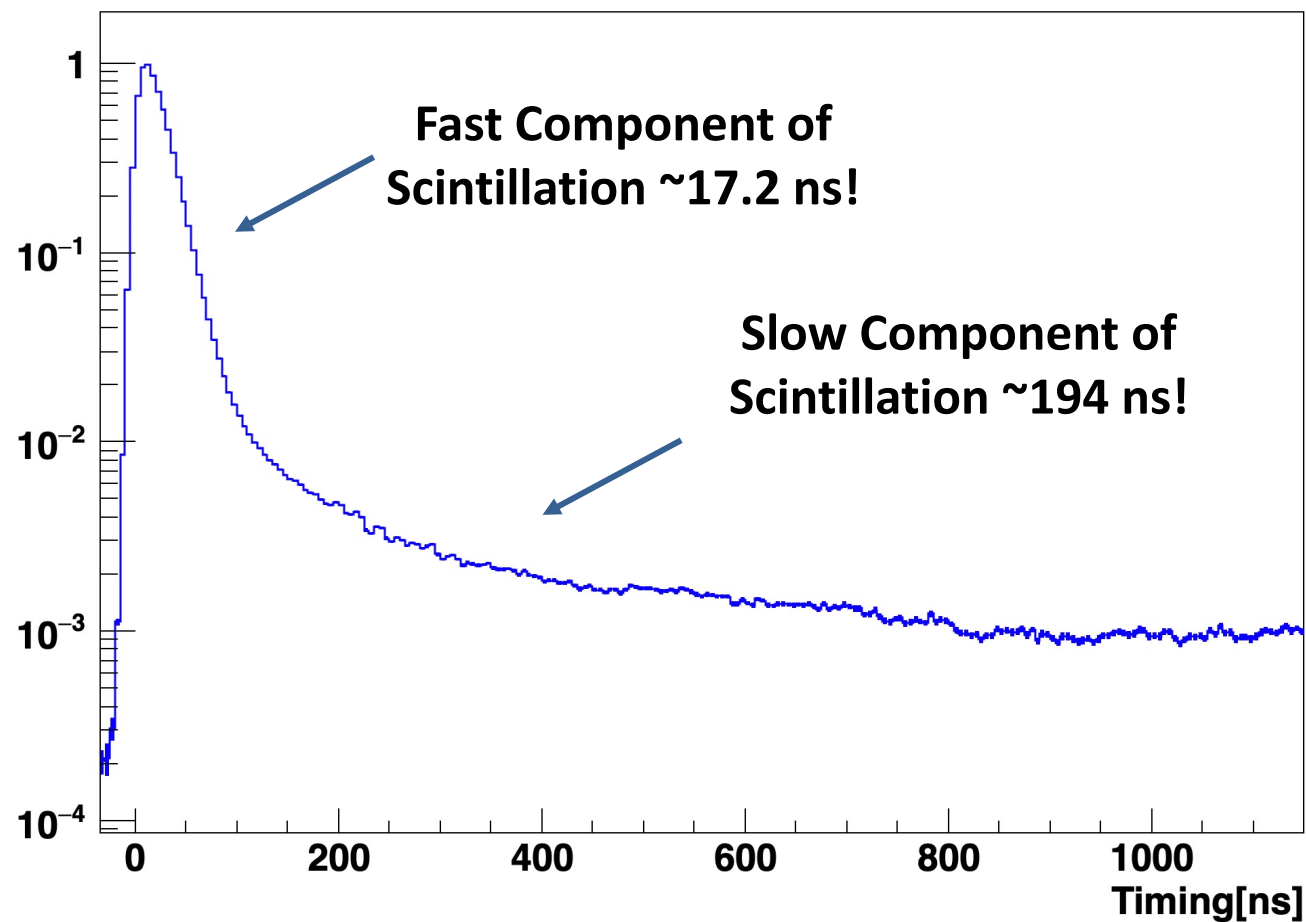


First Demonstration of PSD in Scintillation Light using WbLS



- Through this work we have developed water-based liquid scintillator with pulse-shape discrimination capability in the scintillation profile.
- This formulation has the capability to distinguish fast-neutrons or proton recoils from electronic recoils which has implications for signal identification and backgrounds reduction in antineutrino detectors.
- The PSD also demonstrates the possibility of observing alpha recoils.

Slower Scintillation Decay Timing



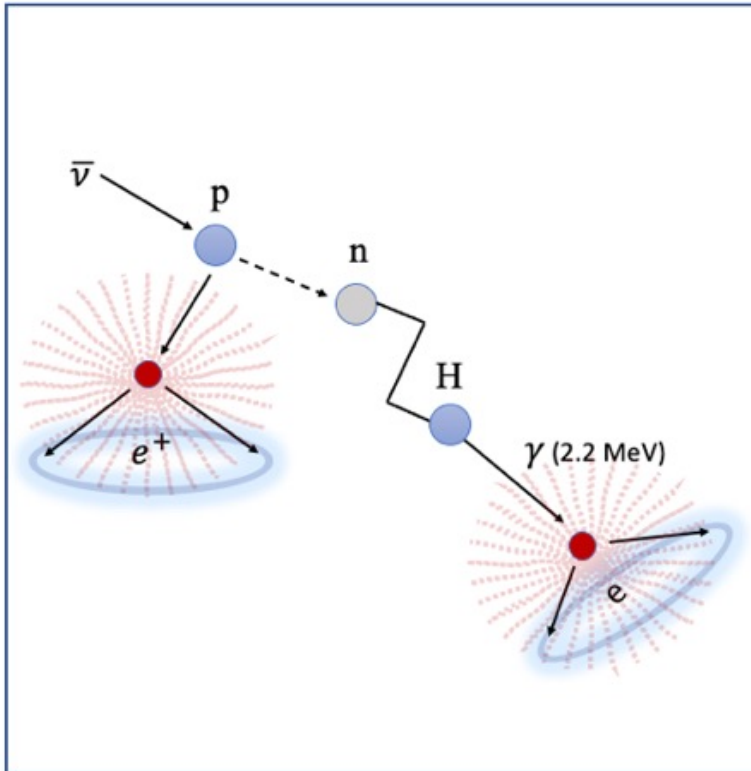
- Cherenkov light is promptly observed in a few nanoseconds, so scintillation decay times on that order require fast-photosensors to resolve the light variations.
- Without optimizing for timing, our formulations exhibit a fast-component decay time of ~17 ns, opening the possibility of normal electronics for Ch/S separation.
- More timing experiments are planned for variable formulations.

WbLS samples	τ_{rise} [ns]	τ_1 [ns]	f_1 [%]	τ_2 [ns]	f_2 [%]	τ_3 [ns]	f_3 [%]
1% LAB/PPO	0.23 ± 0.06	2.00 ± 0.03	87	12 ± 1	6.8	110 ± 10	6.2
5% LAB/PPO	0.23 ± 0.04	2.00 ± 0.02	88	10.0 ± 0.6	6.6	106 ± 6	5.7
10% LAB/PPO	0.29 ± 0.03	2.22 ± 0.03	89	10.7 ± 0.9	6.0	102 ± 9	5.5

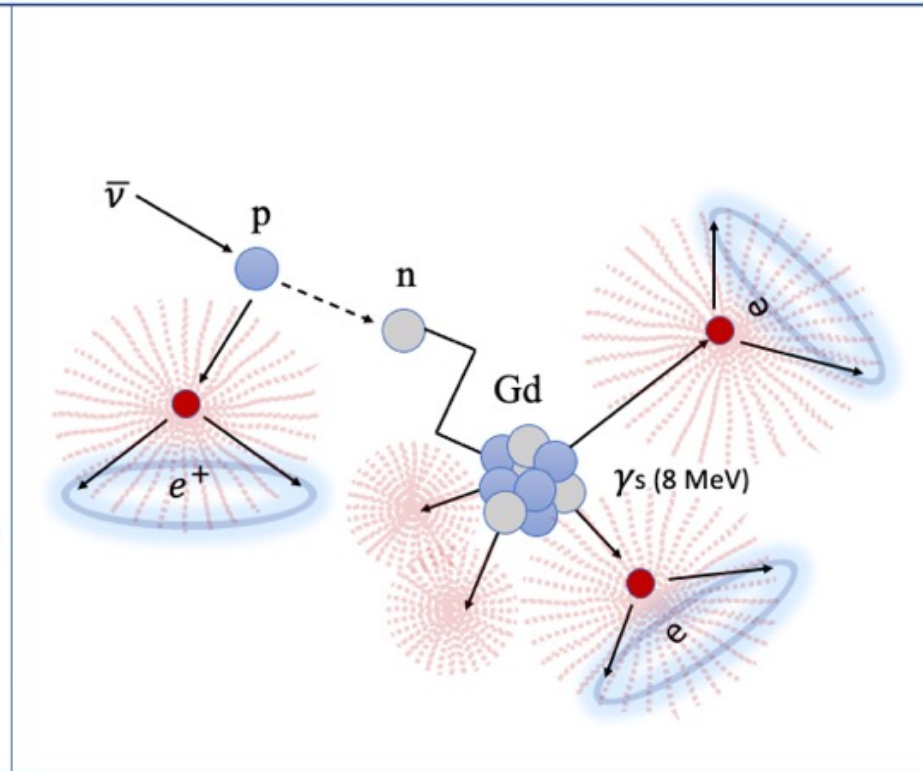
Onken, Drew R., et al. *Materials Advances* 1.1 (2020): 71-76.

Inverse-beta decay detection with various dopants

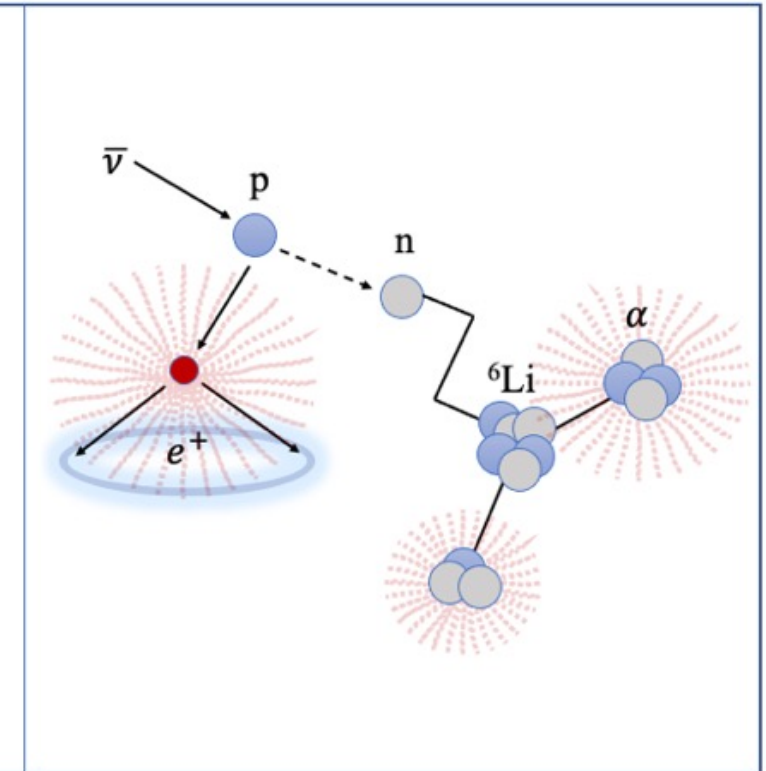
Neutron Capture on Hydrogen



Neutron Capture on Gadolinium



Neutron Capture on Lithium



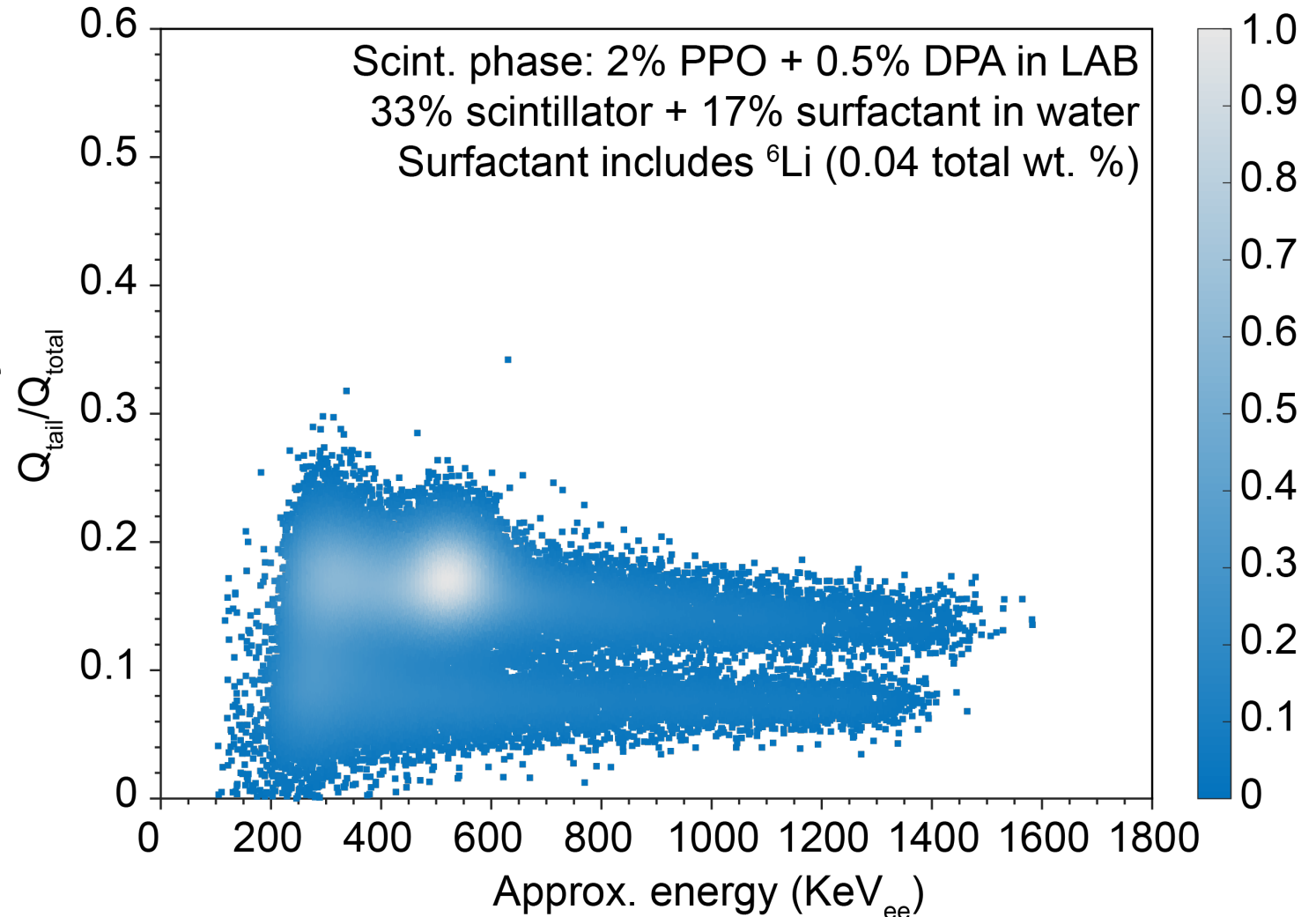
If IBD is not your primary goal and inherent with other dopants.

Typical neutron dopant for IBD detection in both scintillator and water

Recently developed for near-field applications and requires PSD

Lithium Doping in “WbLS”

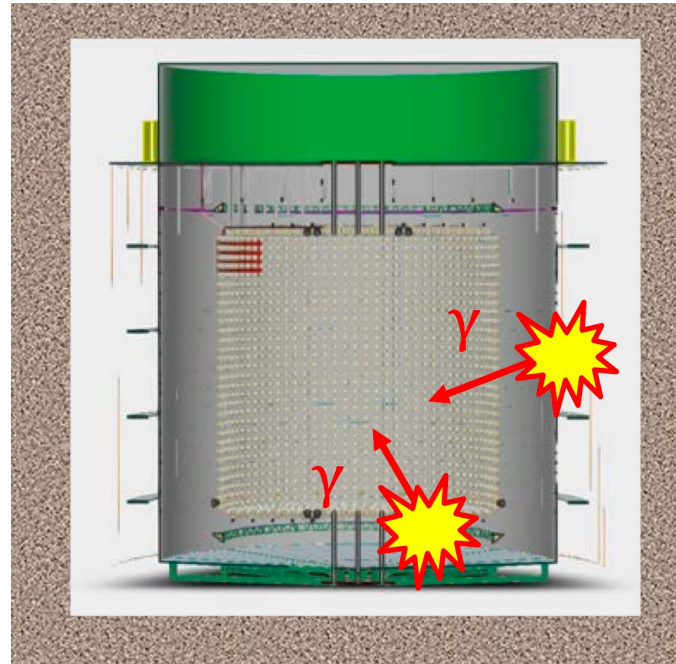
- As part of the work on WbLS formulations we are developing WbLS with Lithium doping.
- These formulations provide a promising progression to a majority water formulation by utilizing Li in the surfactant which can reduce the purification constraints.
- The alpha-triton signature also provides insight to the response to (alpha, n) backgrounds.
- Lithium doping can also allow for better particle reconstruction due to the localization of the event.



Broader impact for antineutrino detection

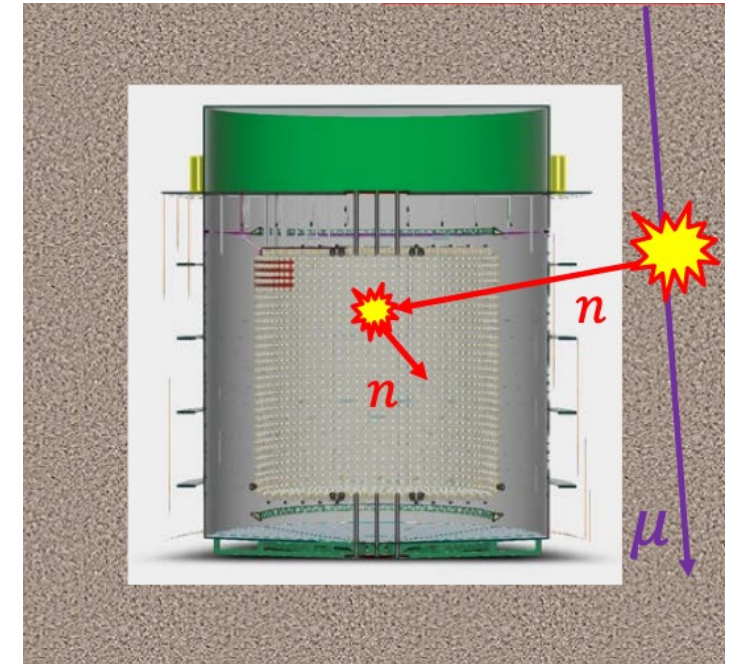
- PSD in large antineutrino detectors can provide an opportunity to reduce contributions from backgrounds that impact the cost of deployment.
- Clear identification of accidentals can reduce the cleanliness requirements for these detectors. Note: Li doping is required.
- Additionally, the ability to identify proton recoils can also reduce the backgrounds from muogenic fast-neutrons.

Accidentals



(γ, γ)

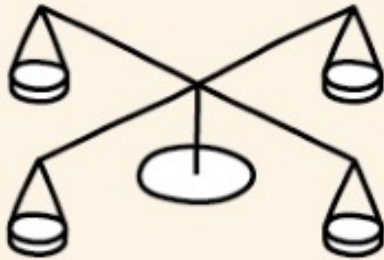
Fast Neutrons



(n, n)

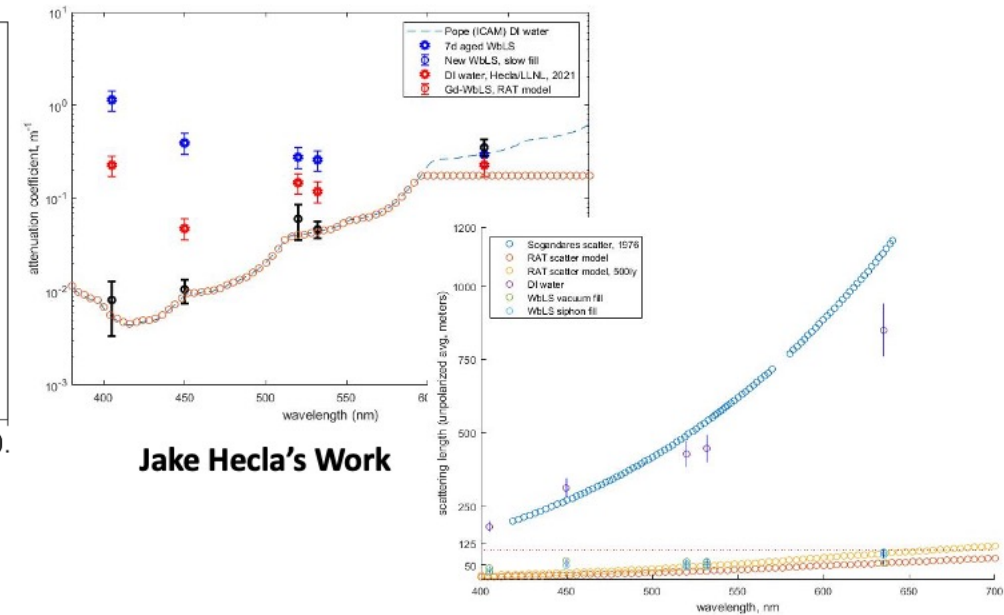
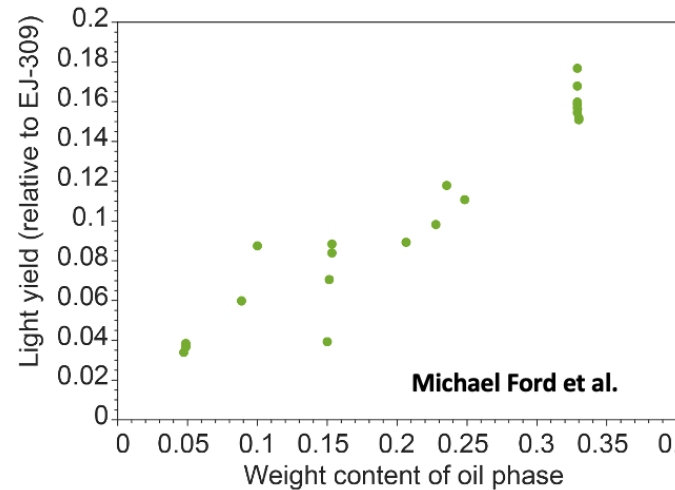
Defining requirements for PSD in Kiloton Scale detectors

Light Yield Fast Decay Time



Attenuation
+ Scattering Slow Decay Time

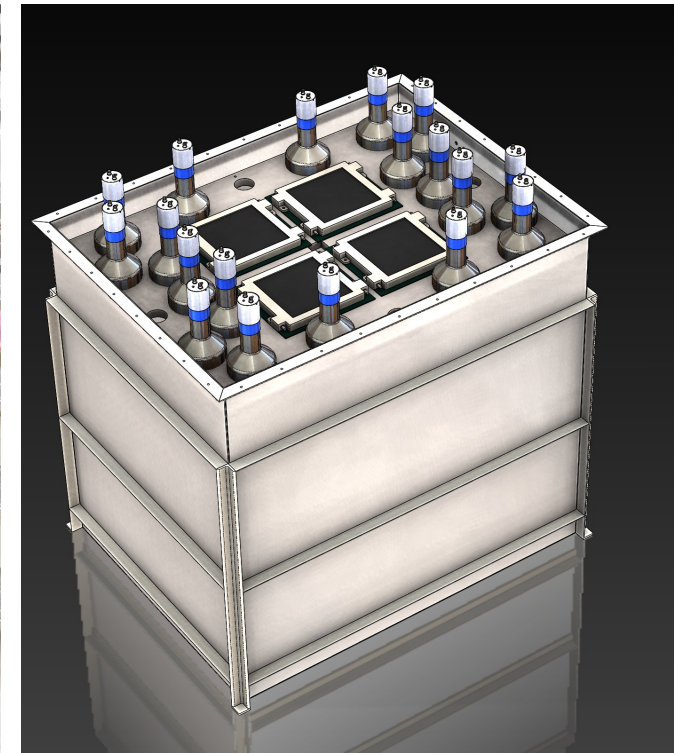
Particle Identification is a Balance



- Observing PSD in large-scale detectors requires a balance of the light yield, fast and slow decay components, and the attenuation and scattering lengths.
- Part of this work is investigating through simulations the limits of PSD in large-scale detectors and informing chemistry for their formulations.

LLNL 1-ton detector refurbishment

- Perform liter-scale tests of LLNL WbLS and LAPPD readout
- LAPPDs Purchased and awaiting characterization.
- Study LLNL WbLS and LAPPD readout in refurbished one-ton LLNL Water-Based Antineutrino Detector (WAND)
- 10" WATCHMAN PMTs (including WbLS-compatible tubes uniquely at LLNL) and LAPPDs will be deployed to validate simulations of LLNL (or other) WbLS performance and Cherenkov/Scintillation separation



Conclusion

- LLNL has demonstrated PSD in water-based liquid scintillator using the scintillation light for the first time. Further development is ongoing to include lithium as a neutron dopant in a majority water formulation.
- Our formulation for WbLS also utilized the HLD method to ensure stable and empirical performance based on the constituent part.
- Experimental work is ongoing to define and validate the physical parameters needed for simulating the response of WbLS in large-scale detectors.

Acknowledgements



More Information about LLNL WbLS can be found:

Ford MJ, Zaitseva NP, Carman ML, Dazeley SA, Bernstein A, Glenn A, Akindele OA. Pulse-shape discrimination in water-based scintillators. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 2022 May 21:166854.

<https://www.sciencedirect.com/science/article/pii/S0168900222003321>

Questions?

Or later contact Tomi Akindele

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